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Factors Influencing Green Construction Practices in Context of COVID-19 Pandemic: Empirical Evidence from China

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Abstract: Green construction practices (GCPs) are essential for the construction industry to achieve carbon neutral and sustainable development. However, the promotion of GCPs faces multifaceted challenges, particularly within the context of recent global uncertainties. The COVID-19 pandemic has wrought substantial disruption upon the construction sector, which makes it a good candidate as a case study for enhancing future risk management strategies. Currently, there is limited research on the factors influencing GCPs in the global uncertainty context. To bridge this research gap, this study first identifies 26 factors affecting GCPs in the context of the COVID-19 pandemic through a comprehensive literature review. Subsequently, based on feedback from 22 experts, Interpretative Structural Modeling (ISM) and Matrice d'Impacts Croisés Multiplication Appliquée à un Classement (MICMAC) methodologies are adopted to illustrate the intricate relationships among influencing factors and further classify their relative importance. The results underscore the pivotal role of factors such as technology development, the difficulty of construction, materials, and equipment performance, as well as identify 13 factors that have a fundamental impact. This research provides insights for decision-makers to enhance risk management strategies for GCPs in the global uncertainty context, prioritize the determinants, and facilitate the optimal allocation of resources to advance GCPs.

Keywords: COVID-19 pandemic; green construction practices; key factors; ISM; MICMAC

Citation: Wang, C.; Xie, X.; Chen, X.; Shuai, C.; Shuai, J.; Strezov, V. Factors Influencing Green Construction Practices in Context of COVID-19 Pandemic: Empirical Evidence from China. *Buildings* **2024**, *14*, 3031. https://doi.org/10.3390/buildings14093031

Academic Editor: Apple L.S. Chan

Received: 30 July 2024
Revised: 15 September 2024
Accepted: 22 September 2024
Published: 23 September 2024

1. Introduction

The construction industry significantly impacts society in environmental, social, and economic dimensions. As a pillar industry of China's economy, this industry has reached a value of RMB 26.39 trillion (USD 3.84 trillion) in 2020. The sector constructed 14.95 billion m^2 of housing and employed over 53.66 million people [1]. In 2021, the value-added output by China's construction industry reached 7% of the gross domestic product (GDP) [2]. Construction activities are notably energy-consuming and emission-intensive, and they generate considerable waste [3]. To mitigate the damage to the environment and further advance sustainable development within the sector, the Chinese government formulated successive regulatory frameworks such as the Law on the Prevention and Control of Solid Waste Pollution [4], the Environmental Protection Law (revised in 2014) [5], the Assessment standard for Green Building [6], the fourteenth Five-Year Plan for the Building Energy Conservation and Green Building Development, and the Green Building Creation Action Plan [7]. Meanwhile, the government has promoted green construction practices (GCPs) through incentives such as taxation, subsidies, and carbon trading mechanisms.

GCPs aim to alleviate the adverse impacts caused by conventional construction activities especially during the construction stage, which consumes the most resources and energy and generates the most waste. GCPs focus on using green construction techniques

(GCTs) or green materials to maximize resource efficiency while ensuring essential requirements such as quality and safety. Globally, green building certification protocols have provided standardized frameworks for enhancing the sustainable performance of construction projects, such as LEED, BREEAM, and WELL, and China's Green Building Label. These certifications align the construction industry with broader environmental and social objectives. However, widespread implementation of these protocols faces challenges such as economic constraints, regulatory differences, and varying levels of market demand across regions. China had constructed more than 6.6 billion m^2 of green buildings and over 23.8 billion m^2 of energy-saving buildings by the end of 2020 [8]. Despite this progress, the transition from conventional construction practices to GCPs remains at an early stage [9]. Experiences of accelerating the development of GCPs in China offer valuable insights not only for the country itself but also for other developing economies globally.

In recent times, the world has been marked by global uncertainties that pose significant challenges to economies and industries. Events such as geopolitical and economic crises, war in the Middle East, conflict between Russia and Ukraine, and the global COVID-19 pandemic have all caused profound impacts. Identifying the critical factors that influence industrial practices is of great significance in the global uncertainty context. Notably, the COVID-19 pandemic posed a profound new threat to all industries [10], which can be taken as a reference for risk management. Such an endeavor is essential for enhancing risk management strategies when facing similar situations in the future.

Globally, governments implemented strict lockdown measures to control the spread of the virus [11,12]. These efforts, while essential for public health, had wide-reaching consequences on the world economy and numerous industries. The global economic downturn led to a slowdown in the construction industry, given its reliance on physical work at construction sites. For instance, in China, the construction industry growth rate in 2020 and 2021 was 2.7% and 2.1%, respectively, which is a considerable decline compared to 3.9%, 4.8%, and 5.2% in 2017, 2018, and 2019, respectively [13]. In April 2020, the UK construction industry experienced a sharp contraction, shrinking by 40.1% [14]. Other countries or regions also reported significant shocks to their construction industries due to the pandemic, including the United States [15], Singapore [12], Malaysia [16], and India [11]. In March 2020, a survey conducted by the Associated General Contractors of America (AGC) revealed that nearly one-third of its members reported project suspension or delay as a result of the COVID-19 outbreak [17]. Similarly, a survey in China showed that 60.95% of the surveyed companies believed that the pandemic negatively impacted their production and annual performance targets [18].

The construction industry is a labor-intensive workforce, and on-site operations have been severely impacted by the pandemic [11,19]. The recession and lockdown led to over 5000 layoffs in the UK construction industry during March and May 2020, while the average unemployment rate in the US construction sector surged by 95% in 2020 [20]. The impact was also evident through the more health and safety requirements for construction workers [19], along with rising labor costs [11].

The construction industry is characterized by substantial energy and resource consumption and a high carbon footprint. The adoption of GCPs can reduce environmental problems, contributing to the achievement of the carbon neutral target. Previous studies have identified influencing factors of traditional GCPs, but limited studies have considered the influences of the pandemic. Research on this topic has focused on analyzing the different impacts generated by the pandemic, with few studies focusing on the relationships between the influencing factors. In addition, there is a research gap in evaluating the impact of the COVID-19 pandemic on the construction industry in China. Further exploration into risk management strategies is also valuable against the backdrop of global uncertainty.

The aim of this paper is to address the above research gaps by identifying and analyzing the factors affecting GCPs in the context of the COVID-19 pandemic. The research questions include the following: (1) What are the critical factors influencing GCPs during the pandemic? (2) What are the interactions of the identified factors, and how can we develop targeted measures to enhance the development of GCPs? (3) How can we provide decision-making references on risk management strategies for the impact of global uncertainty on the construction industry? The main contributions of this study are as follows: (1) Identifying 26 influencing factors of GCPs relating to COVID-19 pandemic, thus providing a clearer understanding of how the pandemic impacts the construction industry; (2) Exploring relationships and the hierarchical structure of these factors, highlighting key elements, and proposing targeted strategies to promote GCP development; (3) Practically providing risk management insights and emphasizing how GCP strategies can be adapted to navigate ongoing global uncertainties and ensure sustainable industry growth.

The rest of the study is structured as follows: Section 2 identifies 26 critical factors through a comprehensive literature review. Section 3 explains the research framework, data, and methodology. Section 4 describes the results, discussion, and implications. Section 5 presents conclusions, limitations, and future directions.

2. Literature Review

This paper first conducted a literature review to summarize existing research efforts and determine relevant factors influencing GCPs in the COVID-19 pandemic context. At first, to retrieve previously published studies and identify influencing factors, Web of Science (WOS), Google Scholar (GS), and China National Knowledge Infrastructure (CNKI) databases were used. The keywords including "construction industry", "green building", "green construction", "green construction technology", "sustainable construction", "COVID-19", "barriers", "obstacles", "influencing factors", and "green practices" were combined using Boolean operators (AND and OR). After removing duplicated literature and scanning the titles and abstracts, 62 papers were selected for full-text reading to select the discussed factors. However, this paper further considered 43 papers and prioritized the identified factors according to the research topic and relevance to the COVID-19 pandemic. After reviewing the selected papers, a total of 26 influencing factors from five perspectives were identified.

2.1. Project Level

The COVID-19 pandemic has unprecedentedly damaged the global economy, leading to significant reductions in both production and consumption [21,22]. The economics of a construction project is a key concern for the owner; the pandemic affected the cash flow of the business, leading to cost-cutting measures that may deprioritize green initiatives [14]. Meanwhile, it caused more uncertainties that affected the economics of the project, such as resource limitations, higher construction material prices, and increased labor costs due to longer construction periods. Generally, GCTs are costly, less profitable, and have longer payback periods than traditional construction methods; thus, the adoption of GCTs entails additional costs [9]. However, from a broader life-cycle perspective, GCTs can mitigate operation costs by saving energy consumption, which helps to offset the upfront cost, especially in the context of rising carbon trading costs and energy prices [3].

Time is another important indicator for construction activities. The pandemic caused off-site construction employees to transition to work from home. Research has found that more flexible remote working has benefits [23]. However, construction activities are labor intensive, the lack of necessary digital infrastructure in companies and difficulties in workforce management can also lead to inefficiencies [24,25]. During the pandemic, delays, temporary shutdowns, material shortages, and additional costs can cause an increasing number of disputes, lawsuits, and claims within the construction industry. This involves relationships including contractor–subcontractor, contractor–supplier, owner–consumer, and contractor–financial institutions.

2.2. Market Level

The green construction market consists of the supply side and the demand side. The former primary includes real estate enterprises, material and equipment suppliers, survey, design, construction, and property management companies [26]. These subjects are directly involved in the construction activities and influence the effect of GCPs. Due to the impact of the pandemic, funding priorities have shifted as governments and organizations focus on immediate recovery efforts, potentially sidelining long-term sustainability goals. During the pandemic, a major problem is the shortage of skilled workers [27]. Rising labor costs, in turn, affect the green construction market [28]. Pandemic lockdowns can also lead to disruptions in the business chain, delayed deliveries, or supply shortages of raw materials and equipment [24,29]. The influencing factors identified from the supply side include materials and equipment, business and supply chain, market competition, uncertainty, and labor.

On the demand side, consumer demand is the guide for the green construction market; the possibility of consumers purchasing green products will directly influence the owner's willingness to adopt GCTs [30]. Studies have proven that consumers' purchase behavior of green products is related to green awareness, purchasing ability, and market promotion [26]. The pandemic has reshaped the building market and driven preference changes for buildings (i.e., enhanced natural ventilation to reduce health risks). Consumers are also seeking better daylighting solutions to promote well-being and energy efficiency, along with flexible working spaces that support remote and hybrid work arrangements. On the other hand, the purchasing power of consumers has been affected by unemployment and reduced incomes. As a result, demand for GCPs fluctuates as consumers focus more on affordability and practicality than on long-term environmental benefits [31].

2.3. Technical Level

The development of GCTs is important to the industry. For different needs, GCTs can be integrated at various project stages for specific objectives such as saving resources, being environmentally friendly, reducing waste pollution, and providing more green space [32]. Some of the important GCTs include renewable energy use, i.e., solar water heating, photovoltaics, and small wind turbines [33,34], as well as green lighting systems, precast concrete technologies, green roofs, energy saving technologies, and waste management [9,35]. In practice, the difference in technology maturity makes implementation more difficult. The reliability of the enterprises' access to information channels about GCTs and information uncertainty are also barriers to GCPs [36,37].

To tackle the environmental issues caused by the use of fossil fuels. The application of renewable energy technologies is essential for reducing emissions [38], achieving green certification [36], and meeting sustainable development goals.

The use of green materials and technologies aids in reducing, recycling, and reusing construction and demolition waste [39]. However, practitioners may adopt conventional construction methods due to performance uncertainties, availability, and applicability limitations of new products and technologies [36].

The normalization of the pandemic also poses new challenges to health and safety in sites [40]. To ensure productivity, contractors need to adopt new measures to provide a safe working environment [14], including safety management, safety training, and necessary personal protective equipment [24].

2.4. Policy Level

Government incentives and guidance are vital to the high-quality development of the construction sector. According to the theory of collaborative governance, collaborative governance between the government and the market is more effective in achieving the efficient allocation of resources. Government environmental legislation and policies play an important role in promoting GCPs [41]. GCPs are essentially a special product with their own economic externalities, and government policy tools such as taxes, subsidies, and carbon trading mechanisms help alleviate them [42]. Government supervision and management mechanisms can ensure that GCPs are regulated by laws and industry norms.

Therefore, the process of GCPs must recognize the relevant constraints from the perspective of the government. Government instructions are critical to address the pandemic crisis in construction [43]. Simultaneously, new governmental regulations responding to the pandemic negatively impact construction activities, such as reducing non-essential construction operations and limiting the gathering of people [24,29].

2.5. Socio-Psychological Level

When analyzing an individual's decision to purchase green housing, it is necessary to take socio-psychological factors into account [3]. Knowledge is a very important variable in behavioral research, significantly influencing people's decisions and behavior. Lack of personal knowledge, awareness, and benefits hinders the adoption of GCPs [44].

Environmental issues are critical in the construction industry, and the number of studies related to green construction is growing rapidly with the development of sustainable development requirements, energy saving, and emission reduction policies. As a traditional industry with high energy consumption and pollution, the construction industry urgently needs to meet new requirements for green sustainability, achieving carbon neutrality and carbon peaking goals [45].

Support from top managers directly influences the adoption of GCTs [46]. The strategic thinking of managers, i.e., forward-looking judgments and insights about the future development of the industry, helps to promote GCPs and thus improve corporate competitiveness.

Stakeholders' environmental awareness is closely related to their attitudes toward the adoption of GCPs; an environmental perspective can lead to a general acceptance of GCTs [47]. Individuals with positive attitudes toward the environment will be more able to accept the risks and uncertainties arising from GCPs [47,48].

The COVID-19 pandemic not only affected people's physical health but also their mental health and well-being. Anxiety is one of the main effects that people suffer during the pandemic. Fear of exposure to the virus, job stability, workload, stress levels, and financial burdens can directly affect workers' minds and bodies [19], further causing depression, stress, confusion, and lack of confidence [21]. The requirement to maintain social distance also limits interactions among workers; lonely workers may be more vulnerable to negative emotions [49].

A conservative organizational culture may have an impact on GCPs. The traditional construction industry has developed very maturely, while GCTs are constantly updating and evolving. Employees may resist and be reluctant to accept new technologies once they get used to the traditional way of working. To summarize, Table 1 presents the identified factors through the literature review process.

Table 1. Factors influencing green construction practices.

Levels	Factors	Descriptions	References
Project	S_1 Costs	Additional costs and time for adopting GCTs	[50,51]
	S_2 Economic	The financial situation of enterprises affected by the pandemic, the economic benefits of GCPs	[3,9,14,21]
	S_3 Remote working	Impact of remote working on project implementation	[24]
	S_4 Contract performance	Contract defaults affected by the pandemic	[24]
Market level (Supply Side)	S_5 Materials and equipment shortage	Shortage of raw materials and machinery caused by the pandemic	[24]
	S_6 Business and supply chain	Business and supply chain disruptions caused by the pandemic lockdown	[19]
	S_7 Market competition and uncertainty	The impact of market competition and market uncertainty	[52–54]
	S_8 labor	Labor shortage due to the pandemic lockdown	[55,56]

Table 1. *Cont.*

Levels	Factors	Descriptions	References
Market level (Demand Side)	S_9 Owner's green willingness	Owners' willingness to accept the higher costs of adopting GCTs	[57,58]
	S_{10} Consumer demand	Likelihood of consumer acceptance and purchase of GCPs	[59,60]
	S_{11} Consumer purchasing power	The possibility of consumers investing in green buildings compared to traditional buildings	[26,30]
	S_{12} Market promotion	Marketing of GCTs	[30]
Technical	S_{13} Technology development	Technical barriers to GCTs	[61]
	S_{14} Difficulty of construction	The difficulty of meeting the environmental requirements of GCPs	[62]
	S_{15} Materials and equipment performance	Material and equipment performance meet the requirements of GCTs	[63]
	S_{16} Risk management	Safety management measures and risk response strategies affected by the pandemic	[24]
	S_{17} Information gaps	Channels, quantity, and availability of information on GCTs	[36,51]
Policy	S_{18} Policy incentives	Policy incentives that motivate stakeholders	[58,64]
	S_{19} Industry specifications	Green construction industry has well-developed specifications	[65]
	S_{20} Laws	Sound laws, regulations, and sufficient enforcement	[58,66–68]
	S_{21} Pandemic regulations	The government's pandemic policies and regulatory requirements	[24,29]
Socio-psychological	S_{22} Managers' awareness	Managers' awareness of green materials and GCTs	[36,58,62,69]
	S_{23} Strategic thoughts	Managers' long-term view and corporate development strategy	[46]
	S_{24} Environmental attitudes	Managers' attitude toward environmental protection and awareness of corporate environmental responsibility	[63]
	S_{25} Mental health	Impact of the pandemic on employees' mental health	[19,21,24,49]
	S_{26} Organizational culture	Employees are used to the traditional way of working and are reluctant to accept new technologies.	[60,70,71]

Source: Authors' compilation from literature.

3. Data and Methods

3.1. Research Framework

Figure 1 presents the research framework of this study. First, the relevant influencing factors are identified through the literature review process (detailed factors are summarized in Table 1 in Section 2). Then, they are applied in the design of a questionnaire survey for experts in the construction field. Data collected from experts are used to explore interrelationships between factors using the ISM method [72] and to categorize their dependencies and drivers using the MICMAC analysis [73].

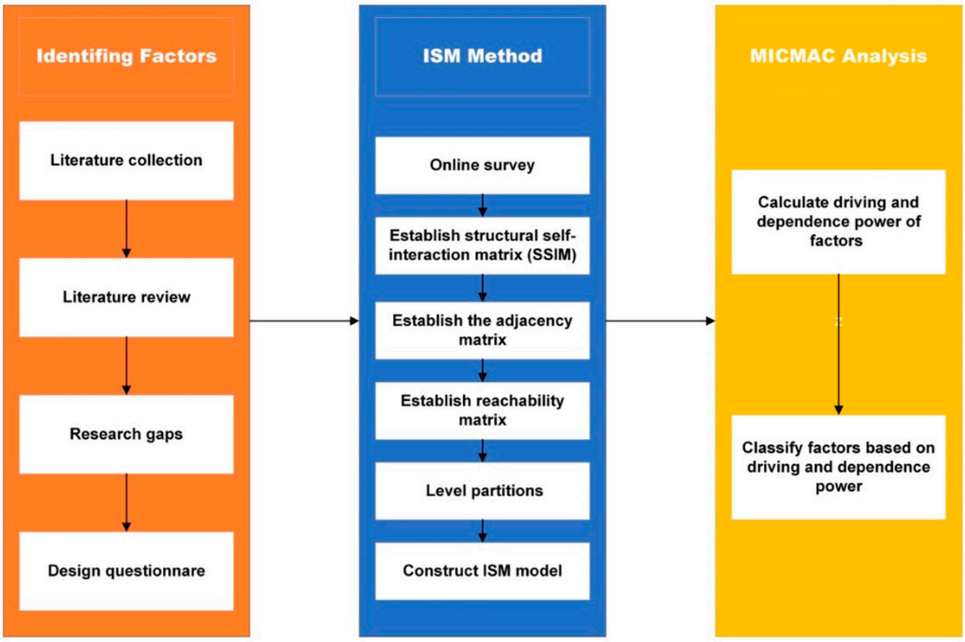

Figure 1. Research framework of this study.

3.2. Data Collection and Descriptive Statistics

Experts' professional knowledge is used to collect, organize, and summarize the key factors and initially determine the influencing relationship between the factors. A questionnaire was designed to collect data from experts in the construction field in China. Random sampling and snowball sampling strategies were adopted [74]. Due to the impact of the COVID-19 lockdown, the questionnaire survey was conducted through an online platform in May 2022. Participation in this study was completely voluntary; respondents were able to share the questionnaire with other persons who were relevant to this topic. After an introduction to the purpose of the study, if participants agree to participate in the survey, they can use a link or scan of the QR code to finish the questionnaire. Part 1 of the questionnaire collects basic information on demographics and work. Part 2 first displays a table of descriptions and definitions of the 26 factors. Then, respondents are required to answer a series of questions about whether they think factor S_i has a direct impact on another factor S_j (i, j = 1, 2, . . ., 26).

A total of 27 respondents from eight different cities in China participated. After excluding 5 invalid questionnaires, 22 samples are finally retained, which is in line with previous studies that used a similar number of expert-based opinions to perform ISM analysis [75–77]. The effective rate of the questionnaire is 81.48%. In summary, there are 18 males and 4 females in the respondents, accounting for 81.8% and 18.2%, respectively. The age distribution of the sample respondents has a larger proportion aged 35–39 years, accounting for 40.9%, with 36.4% of respondents aging 40–44 years, 4.5% in the group of 45–49 years, and 18.2% of those aged 50–54 years.

The education level of respondents is relatively high, with 68.2% of the total survey samples having a bachelor's degree and 9.1% having a postgraduate degree. Among the work units, construction units account for a larger proportion of about 77.3%, universities or scientific research account for 9.1%, and other units account for the other 13.6%. Among the technical titles of the respondents, senior engineers account for the highest proportion of 72.7%, intermediate engineers and engineers account for 13.6% and 9.1%, respectively, along with one associate professor. Regarding the respondents' roles in construction projects, mid-level managers have a larger share of about 59.1%, followed by 22.7% for staff and 9.1% each for researchers and senior managers.

Overall, respondents have long working experiences in the construction industry. The sample respondents who work in the construction industry for 10–14 years account for 31.8% of the total survey sample size, 31.8% work for 15–19 years, and 18.2% work for 20–24 years, while 9.1% of the respondents work for 25–29 years and 9.1% work for 30–34 years.

The largest number of respondents are involved in 1–2 green construction projects, accounting for 40.9%, followed by 27.3% of those who have been involved in 3–4 projects. The percentage of respondents being involved in 5 or more projects is 22.7%. In contrast, 2 respondents have not been involved in green construction projects before. The descriptive statistics of the respondents are presented in Table 2.

Table 2. Descriptive statistics of the sample.

Variable	Description	Frequency	Percentage
Gender	Male	18	81.8
	Female	4	18.2
Age	35–39	9	40.9
	40–44	8	36.4
	45–49	1	4.5
	50–54	4	18.2
Educational background	Junior college and below	5	22.7
	Bachelor's degree	15	68.2
	Postgraduate	2	9.1
Work unit	Construction unit	17	77.3
	Universities or research institute	2	9.1
	Other units	3	13.6
Technical title	Engineer	2	9.1
	Intermediate engineer	3	13.6
	Senior engineer	16	72.7
	Associate professor	1	4.6
Job role	Senior managers	2	9.1
	Mid-level managers	13	59.1
	Staff	5	22.7
	Researchers	2	9.1
Years of experience	10–14	7	31.8
	15–19	7	31.8
	20–24	4	18.2
	25–29	2	9.1
	30–34	2	9.1
Number of participated green construction projects	0	2	9.1
	1–2	9	40.9
	3–4	6	27.3
	5 and above	5	22.7

Source: Compiled by the author.

3.3. Methods

3.3.1. Interpretive Structural Modeling (ISM)

In terms of methodological choices, while principal component analysis, exploratory factor analysis, and structural equation modeling are commonly used for factor studies, a large sample of respondents is required [77]. Considering that this study identified 26 factors, it is challenging to collect detailed and reliable data in the pandemic context. On the contrary, the ISM method constructs a systematic and multilevel hierarchical structural model of a system by establishing relationships between elements [53]. It is widely recognized as a structured modeling technique used to analyze problems from macro to micro scales [78]. This model effectively translates complex thoughts and perceptions into intuitive and well-structured models, making it particularly valuable for qualitative analysis in areas such as energy, regional economy, and resource planning [66].

Specifically, the ISM model demonstrates several key advantages. Firstly, it has practical applicability as it does not need large-scale datasets. Secondly, it effectively manages complex relationships among multiple factors by establishing a hierarchical structure, clearly revealing the position of different factors within the system. This capability allows for the identification of underlying factors and core issues. Thirdly, the ISM model exhibits strong flexibility. It can combine with the MICMAC method to systematically illustrate relationships between elements, thereby enhancing both the depth and breadth of research [79].

The ISM model consists of the following steps:

Step 1: Establish a structural self-interaction matrix (SSIM). Based on the questionnaire collected from 22 experts in the green construction field, the interrelationships between the findings and the factors are combined and represented symbolically to obtain the SSIM (S_{ij}). The interrelationships between the factors (i, j) are represented by letters "V", "A", "X", and "O", with the following meanings: "V" represents that factor S_i influences factor S_j, "A" represents that factor S_j influences factor S_i, "X" represents that factor S_i and factor S_j influence each other, while "O" represents that factors S_i and S_j have no influence on each other.

Step 2: Establish the adjacency matrix. The SSIM is then converted into a binary matrix named the adjacency matrix by replacing "V", "A", "X", and "O" with 1 and 0. If factor S_i has an impact on S_j, then the R(i, j) = 1; otherwise, if factor S_i has no impact on S_j, R(i, j) = 0 [80,81].

Step 3: Establish a reachability matrix. The reachability matrix makes it possible to identify the reachability and antecedent sets for each variable [80]. It is used to describe how many elements that S_i passes through to affect S_j, indicating whether there is an interaction between all factors. For instance, if a variable A is related to B and B is related to C, then A is necessarily related to C. In this study, MATLAB R2016a software is utilized to calculate the reachability matrix by determining the indirect influences between the considered variables and marking with 1 when they are determined.

Step 4: Level partitions. The reachability matrix is used to break down the factors into different levels. Interval decomposition divides factors into independent subsystems with no direct influence between them, while inter-level decomposition organizes them into different levels based on their relationships. In this process, the transitivity matrix is transformed into a conical matrix format to manage the factors according to their levels [72]. The reachability set for factor A includes A and any other factors it influences. The antecedent set for factor B consists of B and any factors influencing it. The top-level factors are those where the reachability set and antecedent set match. Once the top level is identified, factors located at that level are removed, and this process repeats until all factors are assigned a level [82].

Step 5: Construct ISM model. The ISM model is developed based on the reachability matrix and structure to draw connections between the influencing factors from each level partition. The factors are explained and illustrated to obtain results with realistic references.

3.3.2. MICMAC

Matrice d'Impacts Croisés Multiplication Appliquée à un Classement (MICMAC) is a method used to analyze the position of the influencing factors in a system and the degree of their mutual influence. After obtaining the ISM model, MICMAC is adopted to further determine the position and role of influencing factors and suggest corresponding countermeasures in a more targeted manner [26]. The dependency and driving power of each of the factors is determined from the reachability matrix, based on the sum of the number of all dependencies in the columns and rows, respectively [81]. A graph is then constructed presenting the dependency power as X axis and driving power as Y axis. According to the drive and dependence power and their positions in the graph, factors are divided into four categories, namely autonomous clusters, dependent clusters, linkage clusters, and independent clusters [83].

4. Results and Discussion

4.1. ISM Model

4.1.1. Structural Self-Interaction Matrix (SSIM)

The SSIM of the factors influencing GCPs based on the survey of the experts is developed, as shown in Table 3. From the influencing factors, 17 are determined to have a single-direction influence, with nine marked as V and eight as A. For instance, S_1 (costs) is identified to have an influence on S_{15} (materials and equipment performance), while S_9 (owner's green willingness) has an influence on S_1 (costs). Only two pairs of factors have influenced each other, i.e., S_1 (costs) and S_2 (economics), S_2 (economics) and S_9 (owner's green willingness).

Table 3. SSIM of factors influencing green construction practices.

	S26	**S25**	**S24**	**S23**	**S22**	**S21**	**S20**	**S19**	**S18**	**S17**	**S16**	**S15**	**S14**	**S13**	**S12**	**S11**	**S10**	**S9**	**S8**	**S7**	**S6**	**S5**	**S4**	**S3**	**S2**
S_1	O	O	O	O	O	O	O	O	O	O	O	A	O	A	O	O	O	V	O	O	O	O	V	O	X
S_2	O	O	O	O	O	O	O	O	O	O	O	A	A	O	O	O	O	X	O	V	O	V	V	O	
S_3	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O		
S_4	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	A	V			
S_5	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	V	O				
S_6	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O					
S_7	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O						
S_8	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O							
S_9	O	O	O	O	O	O	O	O	O	O	O	A	O	O	O	O	O								
S_{10}	O	O	O	O	O	O	O	O	O	O	O	O	O	O	V	O									
S_{11}	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O										
S_{12}	O	O	O	O	O	O	O	O	A	O	O	O	O	O											
S_{13}	O	O	O	O	O	O	O	O	O	O	O	O	O												
S_{14}	O	O	O	O	O	O	O	O	O	O	O	O													
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S_{24}	O	O																							
S_{25}	O																								

4.1.2. Adjacency Matrix

Table 4 shows the adjacency matrix illustrating the interrelationships between the factors influencing GCPs. The adjacency matrix shows that the most direct influencing factor is S_2 (economics), which directly influences the other four factors (S_1, S_9, S_{14}, and S_{15}). The other influencing factors are S_1 (costs), S_4 (contract performance), and S_9 (owner's green willingness), with influences on the other three factors each, while the factors S_5 (materials and equipment shortage), S_7 (market competition and uncertainty) and S_{12} (market promotion) have influences on other two factors each. Factors S_{22} (managers' awareness) and S_{23} (strategic thoughts) have a direct influence on one factor, while the remaining 17 factors are found to have no direct influence on any other factor.

S_2 (economics) is also found to be the most influenced factor, as it is directly influenced by the other five factors. S_1 (costs) and S_{15} (materials and equipment performance) are the next influenced factors; each is directly influenced by the other three factors. In contrast, 13 factors are perceived as not directly influenced by any of the presented factors.

Table 4. Adjacency matrix of factors influencing green construction practices.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_1	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}	S_{18}	S_{19}	S_2	S_{21}	S_{22}	S_{23}	S_{24}	S_{25}	S_{26}
S_1	1	1		1					1																	
S_2	1	1		1	1		1		1																	
S_3			1																							
S_4				1	1																					
S_5					1		1																			
S_6				1		1																				
S_7							1																			
S_8								1																		
S_9		1							1																	
S_1										1		1														
S_{11}											1															
S_{12}												1														
S_{13}	1												1													
S_{14}		1												1												
S_{15}	1	1							1						1											
S_{16}																1										
S_{17}																	1									
S_{18}												1						1								
S_{19}																			1							
S_2																				1						
S_{21}																					1					
S_{22}																						1	1			
S_{23}																							1			
S_{24}																								1		
S_{25}																									1	
S_{26}																						1				1

Note: Values in the blank space are 0.

4.1.3. Reachability Matrix

Table 5 presents the reachability matrix, which considers both direct and indirect influences of the factors. When all influences are considered, factor S_7 (market competition and uncertainty) is perceived as the most influenced factor as it is influenced by nine other factors, followed by S_5 (materials and equipment shortage), which is influenced by eight other factors and S_4 (contract performance) with influences from other seven factors.

Table 5. Reachability matrix of factors influencing green construction practices.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_1	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}	S_{18}	S_{19}	S_2	S_{21}	S_{22}	S_{23}	S_{24}	S_{25}	S_{26}
S_1	1	1		1	1		1		1																	
S_2	1	1		1	1		1		1																	
S_3			1																							
S_4				1	1		1																			
S_5					1		1																			
S_6				1	1	1	1																			
S_7							1																			
S_8								1																		
S_9	1	1		1	1		1		1																	
S_1										1		1														
S_{11}											1															
S_{12}												1														
S_{13}	1	1		1	1		1		1				1													
S_{14}	1	1		1	1		1		1					1												
S_{15}	1	1		1	1		1		1						1											
S_{16}																1										
S_{17}																	1									
S_{18}												1						1								
S_{19}																			1							
S_2																				1						
S_{21}																					1					
S_{22}																						1	1			
S_{23}																							1			
S_{24}																								1		
S_{25}																									1	
S_{26}																						1	1			1

Note: Values in the blank space are 0.

There are ten factors (S_3, S_8, S_{11}, S_{16}, S_{17}, S_{19}, S_{20}, S_{21}, S_{24}, S_{25}) identified in the literature as important factors for GCPs, which are not perceived as either influencing or being influenced by any other factor in the current study.

4.1.4. Level Partition

When considering both direct and indirect influence, the 26 factors are further decomposed into five levels based on the level of influence, as shown in Table 6. The factors from the technical level identified in Table 1 (S_{13}, S_{14}, and S_{15}) are perceived as the most influencing factors, as they have an influence on six other factors. These factors occupy the top level 5 in Table 6. The first two factors from the project level of factors (S_1 and S_2), including S_9 from the market demand side level, are the next most influential factors, with all three factors influencing five other factors. Factors occupying level 4 are perceived to have an influence on three other factors. S_4 and S_{26} both influence two other factors and they form level 3. The group of factors from level 2 (S_5, S_{10}, S_{18}, and S_{22}) influence one other factor. In contrast, the group of factors in level 1 is considered to have no direct or indirect influence on any of the other factors.

Table 6. Level partitions of factors influencing green construction practices.

Levels	Factors
L_1	S_3, S_7, S_8, S_{11}, S_{12}, S_{16}, S_{17}, S_{19}, S_{20}, S_{21}, S_{23}, S_{24}, S_{25}
L_2	S_5, S_{10}, S_{18}, S_{22}
L_3	S_4, S_{26}
L_4	S_1, S_2, S_6, S_9
L_5	S_{13}, S_{14}, S_{15}

4.1.5. Construct ISM Model

The ISM model of the influencing factors of GCPs is further constructed based on the level partition results, as shown in Figure 2.

The 13 factors at the bottom level, level 1, are remote working (S_3), market competition and uncertainty (S_7), labor (S_8), consumer purchasing power (S_{11}), market promotion (S_{12}), risk management (S_{16}), information gaps (S_{17}), industry specifications (S_{19}), laws (S_{20}), pandemic regulations (S_{21}), strategic thoughts (S_{23}), environmental attitudes (S_{24}) and mental health (S_{25}). These factors can be considered as basic and direct factors affecting the promotion of GCTs. The findings are similar to previous studies [24,52–54]. To promote GCPs, the above factors have a fundamental and deep influence and are the problems that need to be solved as a priority. If there is a lack of sufficient attention to the deep risk factors, it is difficult to effectively manage them.

There are 10 factors in the middle levels, level 2, level 3, and level 4, which are materials and equipment shortage (S_5), consumer demand (S_{10}), policy incentives (S_{18}), managers' awareness (S_{22}), contract performance (S_4), organizational culture (S_{26}), costs (S_1), economic (S_2), business and supply chain (S_6) and owner's green willingness (S_9). These factors are indirect influences and have a cascading relationship. They depend on the underlying influences and pass upward to the top influences. These intermediate layers transmit influences that not only affect other factors but are also affected by other factors. Therefore, several factors related to policy changes or market dynamics may be highly deterministic and need to be given extensive attention in response to future uncertainties, e.g., consumer demand and policy incentives.

There are three factors in the top level, level 5, namely technology development (S_{13}), difficulty of construction (S_{14}), and material and equipment performance (S_{15}), all closely related to technological advancements. These factors are the most superficial barrier factors affecting the promotion of GCPs and the ultimate influence target of the system. However, these problems need to be solved through other factors from the bottom and middle levels. For example, driving technological advancements can be achieved by synergies efforts of other factors such as stimulating market demand, policy incentives, proactive promotion, innovative organizational culture, strategic thinking among managers, and reducing technology application costs.

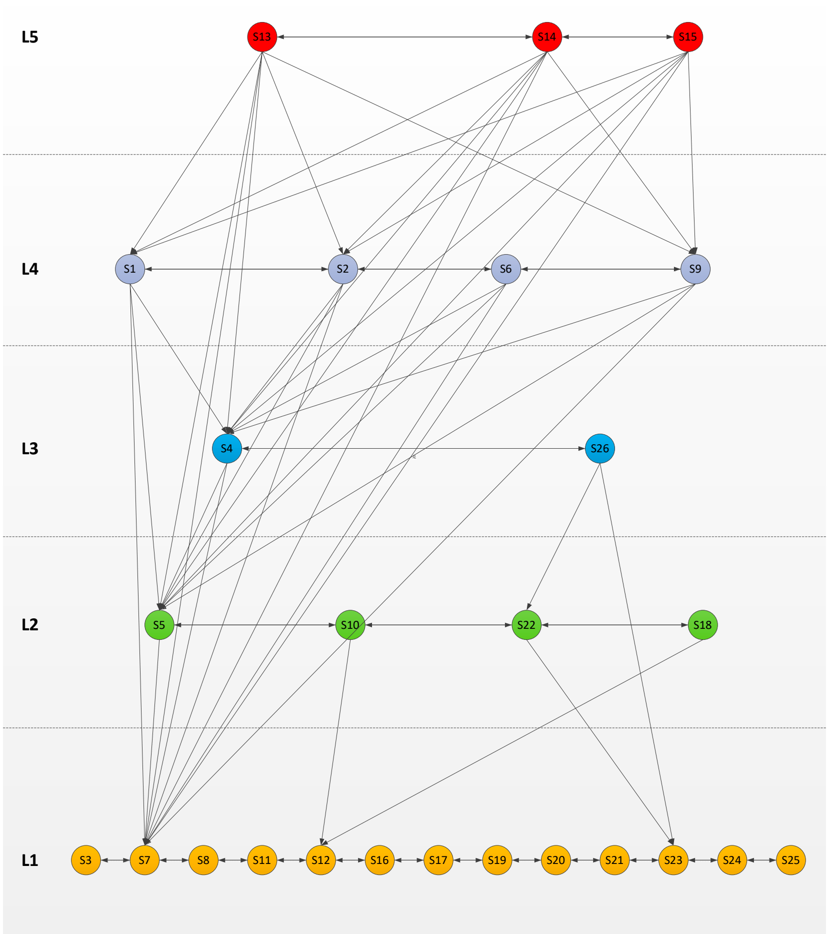

Figure 2. ISM model of factors influencing green construction practices.

Furthermore, the pandemic has sustained impacts on the construction industry, particularly evident at the economic level: measures to address public health crises have increased national fiscal expenditures, thereby affecting public investments and economic stimulus policies for the construction sector. Nations, industries, and companies all need to adjust to economic recovery under the impact of the pandemic. They are likely to exercise more caution in investment decisions in the near future, reducing investments in non-priority projects and conducting stricter risk assessments. At the project level, there is a need to address increased cost pressures resulting from labor and material shortages.

The pandemic has exposed vulnerabilities in the global construction industry and markets, potentially leading to a short-term contraction in business and markets, reduced consumer demand, intensified competition among enterprises, and decreased project profit margins. However, future market demand for green construction is expected to gradually recover. Similar influencing factors are likely to reappear during similar uncertain events, necessitating enhanced risk management in the construction industry. For instance, the industry can enhance supply chain resilience by localizing procurement, diversifying alternative materials and technologies, and strengthening technological innovation to improve core competitiveness and adapt to economic fluctuations.

4.2. MICMAC Analysis

The purpose of MICMAC is to analyze the drive power and dependence power of factors. Dependence power is the sum of the columns "1" corresponding to each factor on the reachability matrix, and drive power is the sum of the rows "1" corresponding to each factor on the reachability matrix [84]. A factor with strong dependence power means that the solution of this factor depends on the solution of other factors, while the strong drive power means that the solution of this factor can help solve other factors. The results from the MICMAC analysis are shown in Figure 3, which illustrates the drive power and dependence power of factors influencing GCPs.

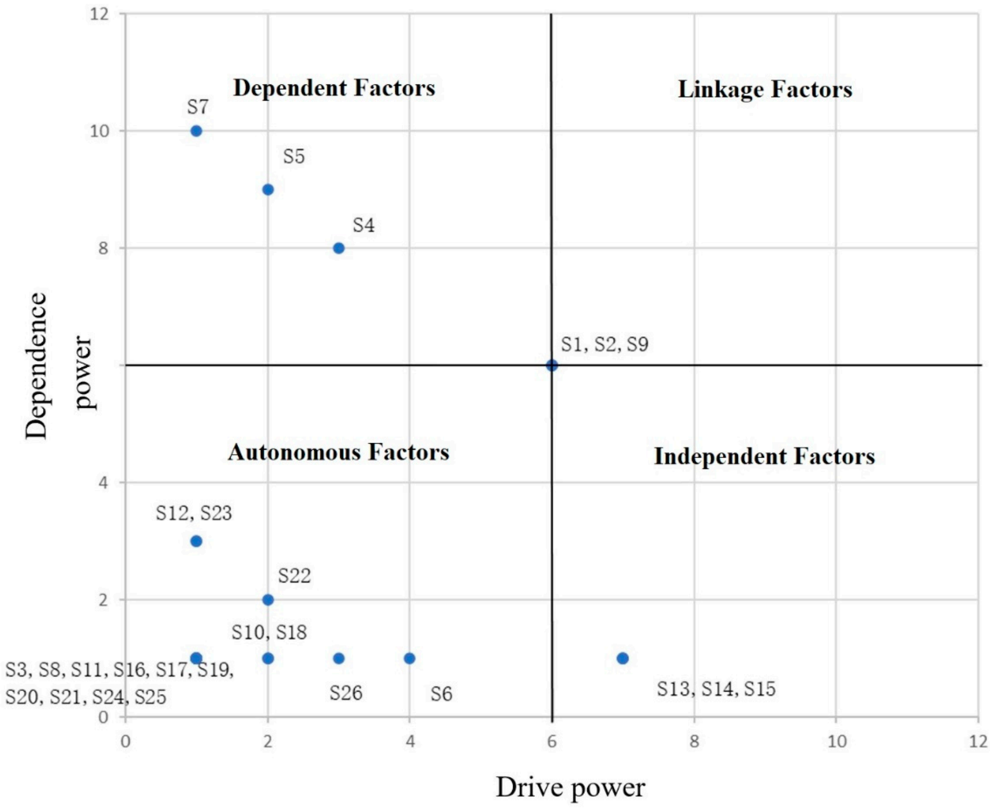

Figure 3. Classification of factors based on drive power and dependence power.

(1) The factors in the first quadrant belong to the autonomous factors. These factors have weak drive power and weak dependence power and typically have simple relationships with other factors. They are mostly located in the middle level of the ISM model, playing a top-down role. The influencing factors in the first quadrant of this study include S_3, S_6, S_8, S_{10}, S_{11}, S_{12}, S_{16}, S_{17}, S_{18}, S_{19}, S_{20}, S_{21}, S_{22}, S_{23}, S_{24}, S_{25}, and S_{26}. Among them, S_6 and S_{26} have relatively strong drive power, which indicates that organizational culture, business, and supply chain are less influenced by other factors but have greater influence on the upper-level factors. Therefore, enough attention should be paid to these factors.

(2) The factors in the second quadrant belong to the independent factors. These factors are deep influencing factors, with strong drive power but weak dependence power, and are located at the highest level in the ISM model. If the factors in this quadrant can be better solved, they will contribute positive effects on the solution of other factors. The independent factors in this study are S_{13}, S_{14}, and S_{15}, which are the same as the factors in the highest level of the ISM model. They are the deep-level factors of the ISM model and the most fundamental and critical factors affecting GCPs [36].

(3) No factors in the results belong to the linkage cluster, indicating no risk factors that are strong for both drive power and dependence power exist. This also means that the selected factors have good stability [85].

(4) The factors in the fourth quadrant belong to the dependent cluster. These factors have weak drive power but strong dependence power, mainly depend on the solution of other factors to be solved. The influencing factors in the fourth quadrant in this study include S_4, S_5, and S_7, which are in the lower-middle level in the ISM model.

It should be noticed that cost (S_1), economic (S_2), and owner's green willingness (S_9) are in the middle of the quadrant; their drive power and dependence power are in a strong position, thus belonging to the core factors [86]. This is also consistent with the results in the ISM model, indicating that these factors are both constrained by the lower factors and can influence the upper factors. Therefore, it is necessary to focus on cost, economics and the owner's green willingness to better promote the development of GCTs.

4.3. Significance and Implications of This Study

In the context of global sustainable development goals, GCPs are being actively promoted, yet they encounter challenges that are common across many countries. This study presents a valuable analytical framework for assessing how unpredictable events affect the construction industry. From a management perspective, this study helps practitioners and managers in the construction industry to realize the goal of sustainable development. It also provides a better understanding of key factors influencing GCPs, the relationships between factors, and the different impact pathways. Accordingly, they can designate appropriate risk management strategies and promotional measures.

Additionally, the framework is adaptable for evaluating key factors influencing GCPs in other regions or different sectors. For example, during times of economic uncertainty, companies worldwide face cost pressures and must innovate to mitigate risks and maintain competitiveness. Companies need to remain flexible, adjusting to shifting policy incentives and regulatory changes to ensure sustainable growth in the sector. Strategic leadership and a strong organizational culture are critical in managing these risks, enabling firms to navigate uncertainty more effectively.

While the empirical findings are specific to the Chinese context, the identified key factors are broadly applicable to the global construction industry's sustainability efforts. For instance, changes in international trade patterns may increase the cost of importing green materials, increasing the initial investment required for GCPs. Companies must optimize procurement processes and enhance material efficiency to manage costs. Moreover, the supply chain disruptions experienced during the pandemic underscore the need for robust risk management. Similar disruptions could occur in the future due to geopolitical tensions, war, or other crises. To mitigate such risks, companies should diversify their supply chains, prioritize local suppliers, and reduce reliance on international markets to better withstand economic shocks.

Although the pandemic has subsided, the insights from this research remain critical for shaping future risk management strategies. The rapid integration of automation technologies in the construction industry is likely to persist, prompting a shift toward remote construction methods and decreasing dependence on on-site labor. Simultaneously, the growing demand for green products emphasizes the importance of staying responsive to evolving market trends. Companies must manage this shift carefully, balancing the immediate cost pressures with the long-term benefits, especially for GCPs, where both initial investments and ongoing operational expenses can be significant.

Additionally, fiscal constraints may cause governments or investors to adopt a more cautious approach to public investment in the construction industry. As a result, direct subsidies or incentives for non-priority projects may be limited. Governments can promote GCPs through other tools, such as targeted policy support, carbon reduction incentives, social reputations, and energy efficiency programs. In response, companies must proactively align their investment strategies with these evolving policies to secure support and remain competitive.

5. Conclusions and Limitations

5.1. Conclusions

Based on previous studies, 26 influencing factors of GCPs in the context of the COVID-19 pandemic are identified through the literature review process. Based on the data from 22 experts, the hierarchical structure of each influencing factor is constructed by the ISM method, and the drive power and dependence power of each influencing factor are analyzed by adopting the MICMAC method. The following conclusions are drawn:

(1) Technology development, difficulty of construction, materials, and equipment performance are the most important factors influencing GCPs in the context of the COVID-19 pandemic. They are located at the top level of the ISM model and belong to independent factors in the MICMAC analysis, which are the factors that need the most attention at the technical level for the promotion of GCPs.

(2) Thirteen factors, including remote working, market competition, uncertainty, and labor, are located at the bottom of the ISM model and have fundamental and deep impacts on GCPs. Seventeen factors in this study belong to autonomous factors, three belong to independent factors, and three factors belong to dependent factors. MICMAC analysis helps to classify these factors as drivers, dependent factors, and link contributing factors while providing a systematic problem-solving idea. If addressing a single factor is challenging, the impact of that factor can be mitigated by solving other factors that have impacts on it.

5.2. Limitations and Future Directions

The main limitation of this study lies in the potential biases in expert feedback and the specific focus on China, while the promotion of GCTs is a global challenge. The priority of influencing factors and the extent of the pandemic's impact may vary significantly across countries due to differences in regulatory frameworks, economic conditions, and environmental objectives. Future research could benefit from considering additional factors from a broader range of perspectives. In addition, conducting localized studies in different countries helps to validate and complement the findings in this work. Furthermore, cross-national comparisons could also provide deeper insights into how the identified factors perform under different socio-political and economic conditions, ultimately contributing to the global advancement of GCPs.

Author Contributions: C.W.: Conceptualization, methodology, formal analysis, data curation, writing—original draft preparation. X.X.: Investigation, data curation, validation. X.C.: Methodology, software, data analysis. C.S.: Supervision, project administration, and funding acquisition. J.S.: Project administration. V.S.: Writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research is supported by the Project of the Natural Science Foundation of China (NSFC) (Grant No. 71773119) and the Humanities and Social Science Project of China's Ministry of Education (Grant No. 21YJC790098). Chaofan Wang acknowledges funding support from the China Scholarship Council-Macquarie University Research Excellence Scholarship (CSC-iMQRES, Nos. 202206410008 and 47484020). Meanwhile, the authors would like to thank all the editors and reviewers for their valuable advice.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

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